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Shelf-life and quality of apple fruits in response to postharvest application of UV-C radiation

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Abstract

In this study, UV-C irradiation (1.435×10^{-4} w cm^{-2}) was used to maintain fruit quality of 'Red Delicious' and 'Golden Delicious' apple cultivars during storage. Apple fruits were irradiated in three different treatments (0, 5 and 15 min), and were stored in a cold storage at 1±1ºC with 85-95% RH for 6 months. At the end of storage, irradiated fruits for 15 min had lower pH and total soluble solids/titratable acids ratio and higher titratable acids and firmness than irradiated fruits for 5 min and control fruits. A significant difference was observed among total soluble solids of irradiated 'Red Delicious' fruits for 15 min, irradiated fruits for 5 min and control fruits at the end of storage. 'Red Delicious' apples had lower total soluble solids and total soluble solids/titratable acids ratio and higher firmness than 'Golden Delicious' apples after 6 months. Our results showed that UV-C irradiation can be used to reduce loss of fruit quality during long period storage of apples.

Key words: UV-C irradiation, apple, 'Golden Delicious', 'Red Delicious', fruit quality.

Introduction

Apple (*Malus domestica* Borkh.) fruits are commonly stored for long periods at low temperatures and under controlled atmosphere. During this period, usually quality and nutritional value of fruit decreases. A number of techniques like prestorage heat treatment (Klein and Lurie, 1992), treatment with chemical compounds (Leverentz *et al.*, 2003) and modified atmosphere (Hertog *et al.*, 2001) have been used. However, some chemical compounds may pose serious health hazard and environmental risks. Additionally, consumers prefer agricultural products without chemicals residues and, hence, alternative methods to control postharvest disease and to extend product shelf-life are required (Marquenie *et al.*, 2003).

UV-C is generally harmful but can produce beneficial effect on horticultural crops at low doses, a phenomenon known as hormesis (the stimulation of plant response by low levels of inhibitors or stress) (Lukey, 1982). UV-C radiation has been shown to be a promising postharvest treatment, because it delays the ripening process and does not affect quality during storage (Maharaj *et al.*, 1999).

Ripening of fruit involves complex physiological changes. The ripening process is generally accompanied by increased pigmentation, sugar, pH, ethylene and decreased firmness, starch and ascorbic acid (Wills *et al.*, 1981). Purohit *et al.* (2003) concluded that Ber (*Zizyphus mauritiana* Lamk.) fruits irradiated for 6 hours with UV-C radiation had lower TSS and TSS/TA ratio and higher TA than other treatments and control fruits. Maharaj *et al.* (1999) and Vicente *et al.* (2004, 2005) also reported increase in fruit firmness due to UV-C irradiation.

This experiment was conducted to examine the effect of UV-C treatment on shelf life and the physico-chemical changes in 'Golden Delicious' and 'Red Delicious' apples.

Materials and methods

'Golden Delicious' and 'Red Delicious' apple fruits were harvested manually on optimal date for commercial harvesting (150 days after full bloom for 'Red Delicious' and 170 days after full bloom for 'Golden Delicious' apples) (Naseri, 2004) from 15-years old standard trees from an orchard in Urmia, Iran, during 2004-2005 growing year. Fruits of uniform shape, size and free from fungal infection were selected.

UV-C radiation was provided by fluorescent germicidal lamp (30 w, 90 cm) with a peak emission at 254 nm. Irradiation was carried out under ambient condition for 0, 5 and 15 min. The intensity of radiation was 1.435×10^{-4} w cm^{-2}. Fruits were placed at approximately 25 cm from the lamp and rotated so that their blossom and stem ends faced the lamp to ensure uniform irradiation. After irradiation, fruits were stored at 1±1 ˚C and 85-95% RH for 6 months. After sampling from cold stored fruits, they were stored for 7 days at 25ºC.

Fruit physical and chemical parameters were measured periodically after treatment and 45 days storage at 1±1 ˚C plus 7 days at 25 ˚C in 12-apples samples per treatment (3 apples per replication) per cultivar. Total soluble solids (TSS) were determined with a hand-held refractometer. Titratable acids (TA) was determined by titration with 0.1 N NaOH and expressed as % malic acid (A.O.A.C, 1980). Fruit firmness was determined on opposite sides of the fruit after peel removal using a penetrometer with 8 mm diameter tip. pH was measured with pH meter. TSS/TA ratio was also calculated.

Completely randomized factorial design with four replications was used. Every replicate had 24 fruits. An analysis of variance was used to analyze difference between means. The Duncan's multiple range test was applied for mean separation at P=0.05.

Results and discussion

Quality measurements revealed that during storage, in irradiated fruits, pH, total soluble solids and TSS/TA ratio increased and firmness and titratable acids decreased slowly than control fruits (Fig. 1). After 6 months storage at 1±1 ˚C plus 7 days at 25 ˚C, irradiated fruits for 15 min had significantly low pH and TSS/TA ratio and high titratable acids and firmness than other treatment and control fruits. Total soluble solids were not affected by UV-C radiation (Table 1). In 'Red Delicious' apples, irradiated fruits for 5 and 15 min had low TSS than control fruits. But in 'Golden Delicious' apples, there weren't significant differences between treatments. Differences for pH between irradiated 'Red Delicious' and 'Golden Delicious' apples were non-significant (Fig. 2).

Table 1. Effect of UV-C radiation on firmness, titratable acids (TA), pH and TSS/TA ratio after 6 months at 1 ± 1 ºC plus 7 days at 25 ºC

Irradiation time (min)	Firmness (N)	TA (%)	pH	TSS/ TA ratio
0 (control)	25.4[c]	0.10[c]	4.57[a]	156.3[a]
5	28.0[b]	0.15[b]	4.22[c]	98.2[b]
15	29.9[a]	0.17[a]	4.44[b]	86.5[c]

Similar letters in columns have no significant differences at $P\leq0.05$.

After 6 months storage at 1±1 ˚C plus 7 days at 25 ˚C, 'Golden Delicious' fruits had high TSS and TSS/TA ratio and low firmness than 'Red Delicious' fruits. pH and TA were not affected by cultivar (Table 2).

Table 2. Effect of cultivar on firmness, total soluble solids (TSS) and TSS/TA ratio after 6 months at 1 ± 1 ºC plus 7 days at 25 ºC

Cultivar	Firmness (N)	TSS (%)	pH
'Red Delicious'	31.85[a]	14.70[b]	107.9[b]
'Golden Delicious'	23.92[b]	15.08[a]	119.4[a]

Similar letters in columns have no significant differences at $P\leq0.05$.

Like other plant development processes, fruit ripening is significantly influenced by growth regulators of which ethylene plays a key role, however, polyamines have also been implicated to control ripening (Pandey *et al.*, 2000; Shamaa and Alderson, 2005). In climacteric fruits, burst of ethylene production is first detectable sign of ripening that occurs during ripening and precedes the respiratory climacteric. During ripening, changes in color and texture are under the control of ethylene whereas flavor development in fruit is not much influenced (Shamaa and Alderson, 2005).

Polyamines are a group of nitrogen-containing compounds that accumulate in plants in response to environmental stress (Evans and Malmberg, 1989; Barka *et al.*, 2000). Polyamines and ethylene may compete for the intermediate S-adenosyl methionine (SAM) which produces the propylamine moiety for their biosyntheses (Pandey *et al.*, 2000; Shamaa and Alderson, 2005). Maharaj *et al.* (1999) showed that optimal doses of UV-C produced higher levels of free and conjugated polyamines particularly putrescine, compared with the control in mature green tomato fruits. Level of putrescine seems to increase in plants subjected to stress and these includes UV irradiation treatments (Shamaa and Alderson, 2005).

The increase in TSS may be related to the moisture loss and hydrolysis of polysaccharides. UV radiation checks the moisture loss, thereby, increasing TSS retardation (Lu *et al.*, 1993).

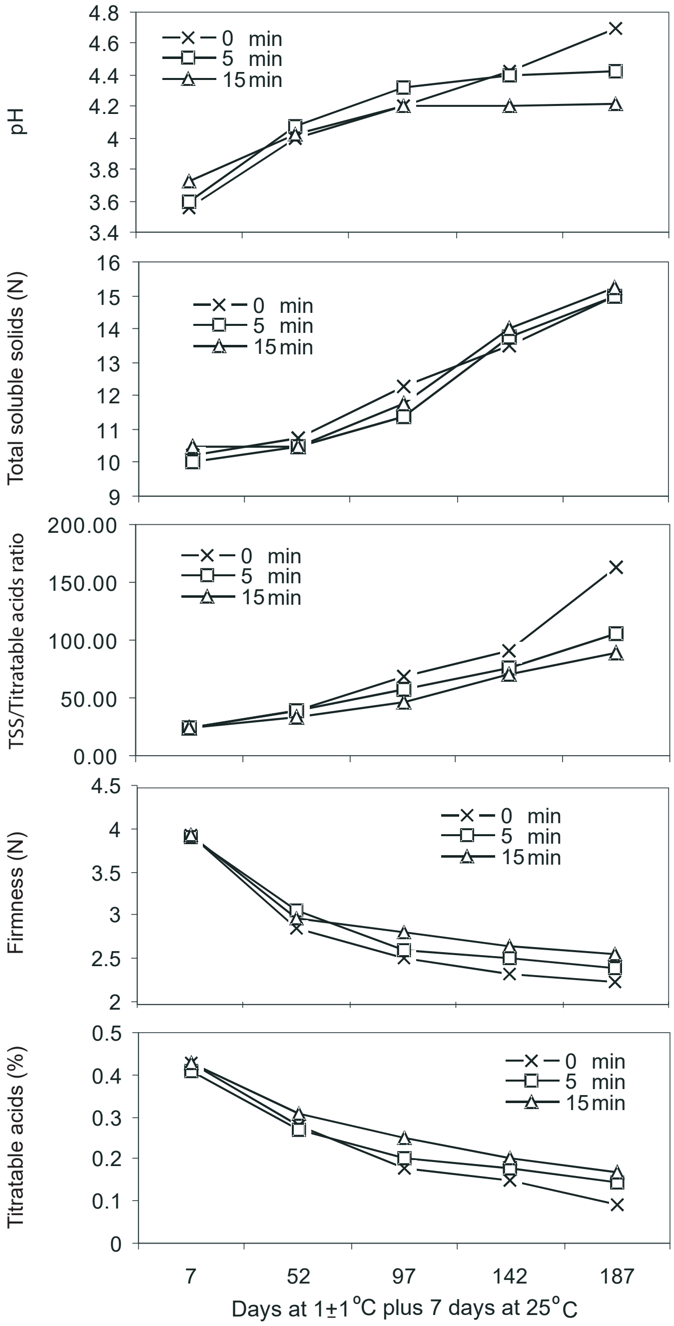

Fig. 1. Changes of pH, total soluble solids, firmness, titratable acids and TSS/TA ratio during storage at 1±1 ºC plus 7 days at 25 ºC.

Fig. 2. Interaction effect of UV-C radiation and cultivar on total soluble solids and pH after 6 months at 1±1 ºC plus 7 days at 25 ºC ($P\leq0.05$).

Therefore, lower rate of increase in TSS of UV-C treated fruits could be attributed to reduced moisture losses and reduced hydrolysis of polysaccharides.

The rate of respiration and ethylene production reduces after UV-C treatment (Maharaj *et al.*, 1999; Vicente *et al.*, 2004). Maharaj *et al.* (1999) suggested that since UV radiation caused a shift in ethylene production rates, the climacteric respiration pattern was also shifted. The shift in ethylene production peak is associated with UV treated fruit suggests that SAM was probably a limiting factor in UV treated fruit. UV could have also caused irreversible membrane deterioration, which could have affected the activity of ACC oxidase (loosely bound to membrane), and thus explain the reduced ethylene production in such fruit (Maharaj *et al.*, 1999).

The higher TA in irradiated fruits could be due to lower respiration rate in the fruits and lower usage of these compounds in respiration process. The lower pH in irradiated fruits is related to high TA in these fruits. The low TSS/TA ratio resulted in higher retention of TA in irradiated fruits.

Maharaj *et al.* (1999) proposed that polyamines play role like conjugation of calcium to pectic acid and other polysaccharides and, therefore, maintain cell wall from hydrolytic enzymes. Additionally, Knee and Bartley (1981) proposed that loss in cohesion of cell walls may result from S-adenosyl methionine methylation of the free carboxylic groups in the pectin material and disruption of calcium cross linkage of adjacent polyuronides. Since SAM is probably routed to polyamines synthesis, it wasn't readily available for disruption of calcium bridges that could lead to increased firmness of the UV treated fruit (Maharaj *et al.*, 1999). Furthermore, Kramer *et al.* (1989) have shown that polyamines inhibit softening by reducing the activity of cell wall degrading enzymes such as polygalacturonase. Barka *et al.* (2000) reported that UV-C treatments could reduce the activity of cell wall degrading enzymes, *i.e.* polygalacturonase, pectin methyl esterase, xylanase, β-D-galactosidase and protease, and delay softening by affecting the cell wall disassembly rate. Reduction in polygalacturonase activity in UV-C treated fruits of tomato was reported by Stevens *et al.* (2004). These could explain the higher level of firmness found in UV-C treated apples.

Present investigation revealed that irradiated 'Red Delicious' fruits for 15 min had higher values of total soluble solids at the end of storage. 'Red Delicious' apples after 6 months had lower total soluble solids and total soluble solids/titratable acids ratio and higher firmness than 'Golden Delicious' apples. The results revealed that UV-C irradiation can be used to reduce losses of fruit quality during long storage period of apple.

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